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“The Challenges on the Development and Sustainable Construction of Infrastructure”

Design Challenges for Offshore Hydrogen Pipelines

Enagás H_2 Technical Day

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Industry Experience

- Longstanding experience in 100% hydrogen pipeline transport.
- Predominantly onshore delivering hydrogen to industrial/ petrochemical plants
- (Mostly) purpose built and designed in accordance with pipelines codes and standards / best practice
  - Pipe material: Steel, typically lower strength API 5L grades (X52 or lower)
  - Typically, low design stresses (30%-50% SMYS) - 87% operated below 50% SMYS
  - 99% are 20-inch or smaller

Region	Onshore (km)	Offshore (km)
U.S.	2,608	-
Europe	1,598	-
Rest of World	337	-
Total	4,542	0

Oil & Gas Pipelines ≈2,120,000km

Codes and Standards

- Hydrogen pipelines are not new, however the codes and standards that govern them are not mature
- Few standards make recommendations against hydrogen specific design challenges
- Development of other standards is underway including DNV, CSA Z662:19, and ASME B31.12
- The DNV H2Pipe JIP (of which Wood is a participant) aims to develop a recommended practice for offshore hydrogen pipeline design and conversion, supplementing DNV-ST-F101

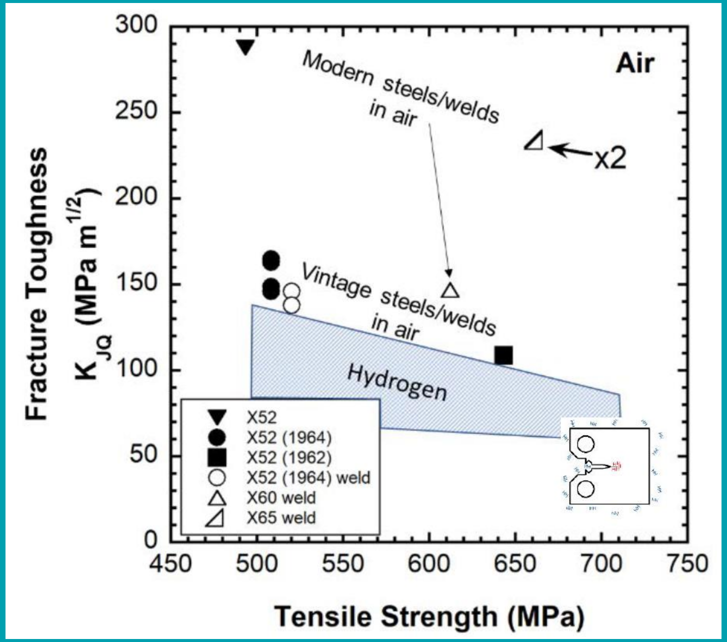
Code	Hydrogen service within scope	Hydrogen specific material requirements considered
ASME B31.12 [1]	✓	✓
IGEM/TD/1 (Sup. 2)	✓	✓
DVGW G 409	✓	✓
API RP 1111	✗	✗
AS/NZ 2885.1 [3]	Update Under Development	
ASME B31.3 [2]	✓	✗
ASME B31.8 [2]	✓	✗
BS EN 14161	✓	✗
BSI PD 8010-1	✓	✗
CSA Z662:19	Update Under Development	
DNVGL-ST-F101	✓	✗
EN 1594	Update Under Development	
ISO 13623	✓	✗
NEN 3650/51	✓	✗

Note:
1) Considered the governing code within the pipeline industry for hydrogen service.
2) Superseded by ASME B31.12 for application to hydrogen pipelines.
3) Guideline for blending hydrogen into pipelines and gas distribution networks under development by Standards Australia

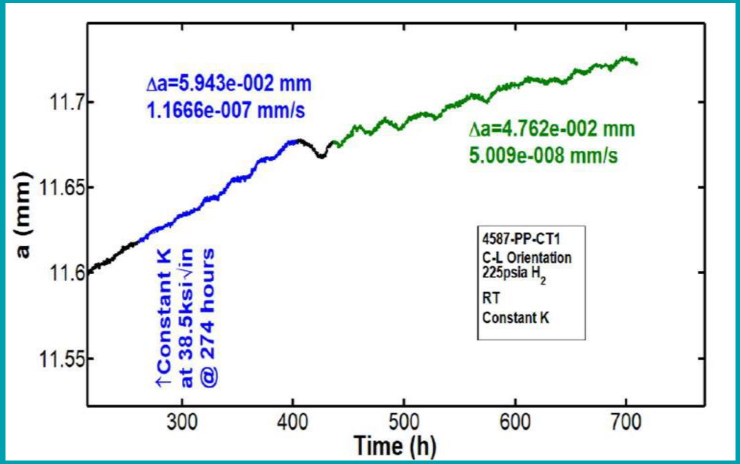
Fracture Toughness & Fatigue Crack Growth

- Hydrogen reduces material resistance (effective toughness) to propagation of pre-existing cracks (e.g. fatigue cracks) under static stress
- Multiple tests have been conducted to display the impact on toughness
- Results indicate strong detrimental effect of hydrogen on effective toughness. 1% hydrogen (0.85 Bara) was as severe effect as 100% hydrogen
- Hydrogen may increase fatigue crack growth rate by factor of 10 to 30 or more relative to in air / gas
- DNV H2Pipe JIP currently ongoing to produce H_2 S/N curve

Sensitivity to Material Grade



Time Dependant Crack Growth

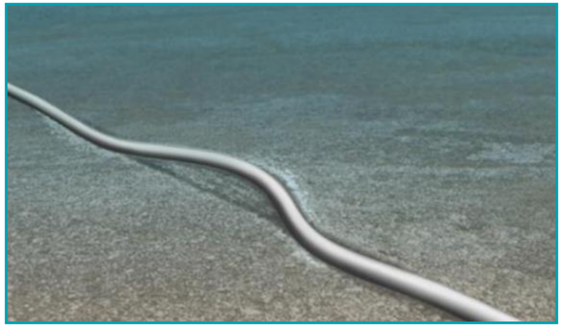


From: Shell (ISOPE, PVP 2023)

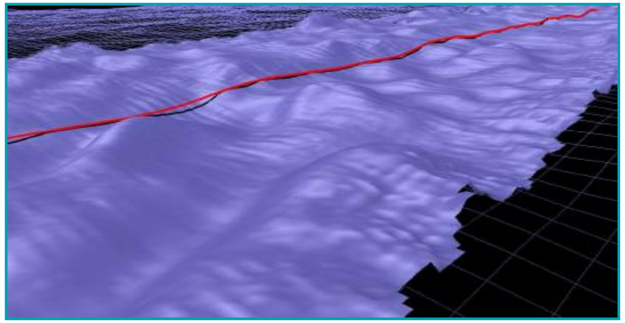
H2 Pipelines – Key Challenges Offshore

- High longitudinal/bending stresses
- High strain loading (e.g. global buckling, accidental loading)
- Fatigue loading (e.g. VIV & storage cycles)
- Definition of allowable Defects and ECA Criteria

High stress design approach offshore will require tighter control of spans and damage than for Natural Gas

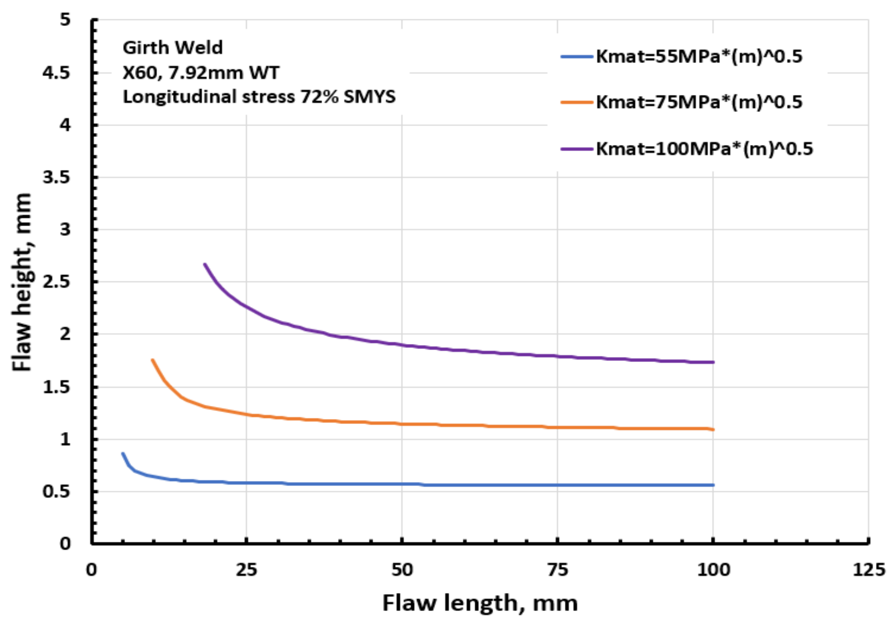


Lateral buckling fatigue subsea

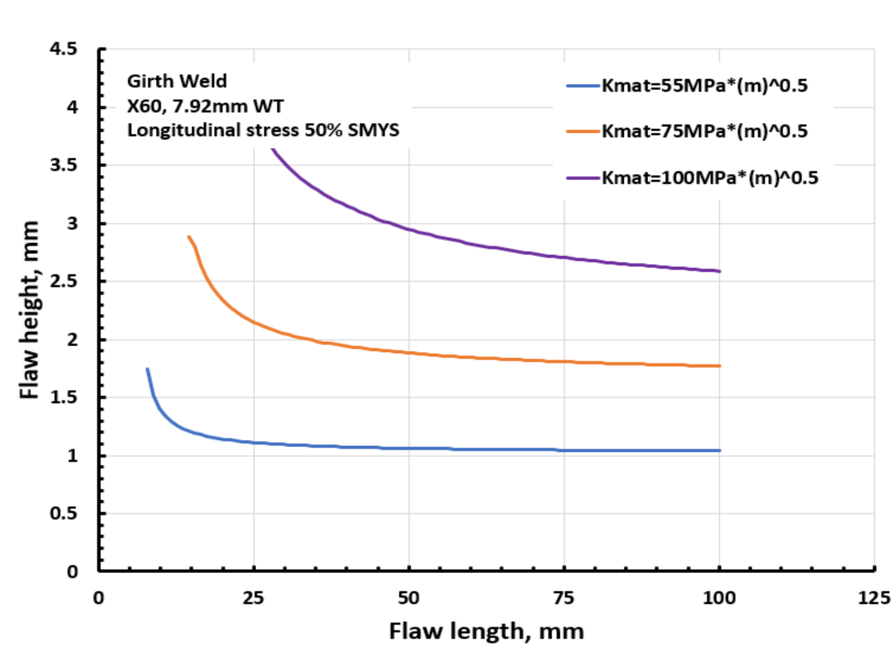


Span fatigue subsea

Case Study ECA – Girth Weld (72 % SMYS)



Case Study ECA – Girth Weld (50 % SMYS)



Summary

- Significant progress has been made over the last years in understanding of the effects of hydrogen environment on materials resistance to fracture and relevant damage mechanisms
- The focus of H_2 conversion work to date has been onshore. Further challenges are anticipated offshore
- The industry is still awaiting widely recognised guidance for the design and specification of subsea pipelines for H_2 service

DNV H2Pipe JIP and DNV-ST-F101 supplement to be released in 2025

Phase 1	Phase 2	Phase 3
2021 - 2023	2023 - 2025	2025
1. FMECA	**1. Special Design scenarios considerations**	
2. State-of-the-art	**2. Effect on H2 on crack growth resistance and deformation capacity**	
3. Guideline	**3. Hydrogen Uptake**	
4. Mechanical Testing	**4. Risk Assessment Study**	
5. Running Fracture	**5. Update on Guideline Document**